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Rock Island Arsenal Laboratory



TECHNICAL REPORT

ORGANIC COATING USING THE
FLUIDIZED BED TECHNIQUE

By

L. O. Gilbert

Pershing Weapon System Project No. 4120.28.5410.1.20.01

Department of the Army Project No. -

Ordinance Management Structure Code No. -

Report No. 62-3183

Copy No. -

IEL -

Date 20 September 1962

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L. O. Gilbert
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Approved by:

A. C. Hanson
A. C. HANSON
Laboratory Director

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Rock Island Arsenal
Rock Island, Illinois

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ORGANIC COATING USING THE FLUIDIZED BED TECHNIQUE

ABSTRACT

The fluidized bed coating process is sometimes referred to as "powder painting" or simply "plastic cladding". Process details, advantages and deficiencies of the process as compared with conventional coating methods, as well as tricks of the trade, are covered. Masking, cold fixturing techniques, patching of the coatings, inspection techniques, machining, and special applications of the coatings are discussed. Use of the process in applying both plastic and metallic coatings reveals an envisioned future application of fluidized bed techniques.

ORGANIC COATING USING THE FLUIDIZED BED TECHNIQUE

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THE COATING PROCESS

The Fluidized Bed Coating Process consists of cleaning, and preheating the object to be coated to a temperature only slightly above the fusion temperature of the coating material being used. The preheated object is then dipped into fluidized powdered plastic material for several seconds. The plastic is maintained in a fluidized condition by an ascending column of dry air. The plastic particles coming into contact with the heated surface sinter to the surface where they fuse to form a smooth continuous surface after being removed from the bed.

Fusion and reflow can only occur if the heat capacity of the part is sufficient to maintain the temperature of the object above the fusion temperature of the plastic after removal of the part from the bed. Should the heat capacity of the object being coated be sufficient to sinter the plastic to its surface, but insufficient to fuse or coalesce the adherent particles, the object is considered to be "sugar coated" and must be post-heated to obtain a satisfactory coating.

Many thermoplastic resins require a two to five minute post-heat to obtain a smooth glossy surface. Most of the thermosetting resins require much longer post-heating to complete the polymerization and "cure" the resin to the infusible state.

Advantages and Disadvantages

Among the advantages of the Fluidized Bed Coating Process are the simple, low cost equipment used, and the ease of automating the entire process to produce uniform quality coatings. However, the most outstanding features of the process are those which permit the application of coatings which by existing painting methods cannot be accomplished without major difficulty or at a reasonably low cost. While other desirable features might be related, the following are the most outstanding.

1. Coatings of 5-40 mils may be applied in production by a single dip without "sags", "runs" or other unsightly defects commonly encountered where the application of heavy paint films in a single coat is attempted.

2. The Fluidized Bed Coating Process permits application of plastic coatings which do not readily lead themselves to solution in solvents for conventional paint application techniques.

3. Unlike paint-films, where the expense of solvents is encountered, the Fluidized Bed Coating Process is a one-hundred percent solvent free system.

4. Electrically insulative coatings may be applied in production by the Fluidized Bed Process to meet specific dielectric levels.

5. Extremely intricately shaped parts, such as wire goods, may be uniformly coated by the Fluidized Bed Coating Process where conventional painting is difficult or almost impossible.

6. The Fluidized Bed Coating Process provides good edge and corner coverage where solvent thinned paints draw back from edges, burrs and weld spatter.

7. The process uses comparatively inexpensive equipment easily adaptable to automation.

To the advantages cited above, many additional advantages might be added but as is inevitably true of all processes, the Fluidized Bed Coating Process has some disadvantages.

Some of the objects such as thin sheet metal or parts having both extremely heavy and light sections are often not ideally suited for coating by the Fluidized Bed Coating Process, but the process provides a very attractive means for coating a large majority of parts.

Following are some of the most important disadvantages:

1. Some plastics tend to be thermally degraded, discolored or charred by the heat required for dipping and are therefore unsuitable for application by this method.

2. Thin, pore free coatings (below 3 to 4 mil) are difficult to maintain on a production line basis.

3. Preheat temperatures needed to apply many coatings will alter heat treatment of some metals, soften or thermally degrade some plastics and other organic materials to which the coating is to be applied, and destroy low melting solder joints.

4. Coating thicknesses are difficult to control on extremely large pieces.

5. Certain curing agents used in some thermosetting coating powders are hygroscopic and must be protected from contact with moisture in the fluidizing air, or in the atmosphere.

6. Special care is required to prevent dust, lint and metal chips or powder from entering the fluidized powder where it deposits with the plastic and becomes incorporated as defects in the coatings.

7. Successful use of the process depends heavily upon the skill and ingenuity of the operator in developing masking and dipping techniques for each specific type of item to be coated.

Many of the above disadvantages will disappear as the skill and experience of the operator improves. However, both the type of equipment and the characteristics of the powder will determine whether even the most skilled operator will be successful in overcoming many of the disadvantages cited.

EQUIPMENT

In its simplest form, the equipment needed consists of preheating apparatus, and the fluidizer, and where certain thermoplastics are involved, a spray or dip cold water quench.

Preheat and Post-Heat Facilities

Preheating poses one of the most difficult aspects of utilization of the Fluidized Bed Process. The facilities selected are determined by the size, the heat capacity, the method of handling the parts through the process, the type of coating being applied and on automated lines, the rate of production required. The preheating equipment may range from a heavy metal heat-sink placed on a hot-plate or gas burner, forced draft ovens, gas fired tunnel ovens, or infrared ovens, to elaborate induction heating equipment.

Consideration must be given to locating the heating facilities close-by the fluidized bed to minimize cooling during transfer to the fluidizer. Where extremely heavy coatings of .050 inch or more are required or where thin stock with low heat capacity is being coated, the necessity for reheating and redipping the parts will usually dictate the use of hand work and forced air ovens.

Small parts which cool very rapidly may be hand dipped by placing them in a heat sink, (Figure 1), and either placing the entire heat sink in the oven or heating the heat-sink on a hot plate or with strip heaters. The entire unit can be located at the very edge of the fluidized bed, thereby minimizing heat loss in transfer and dipping. In such instances, the part after coating is not reinserted in the heat sink but is placed in an oven if reflowing of a thermoplastic or curing of a thermosetting resin is required.

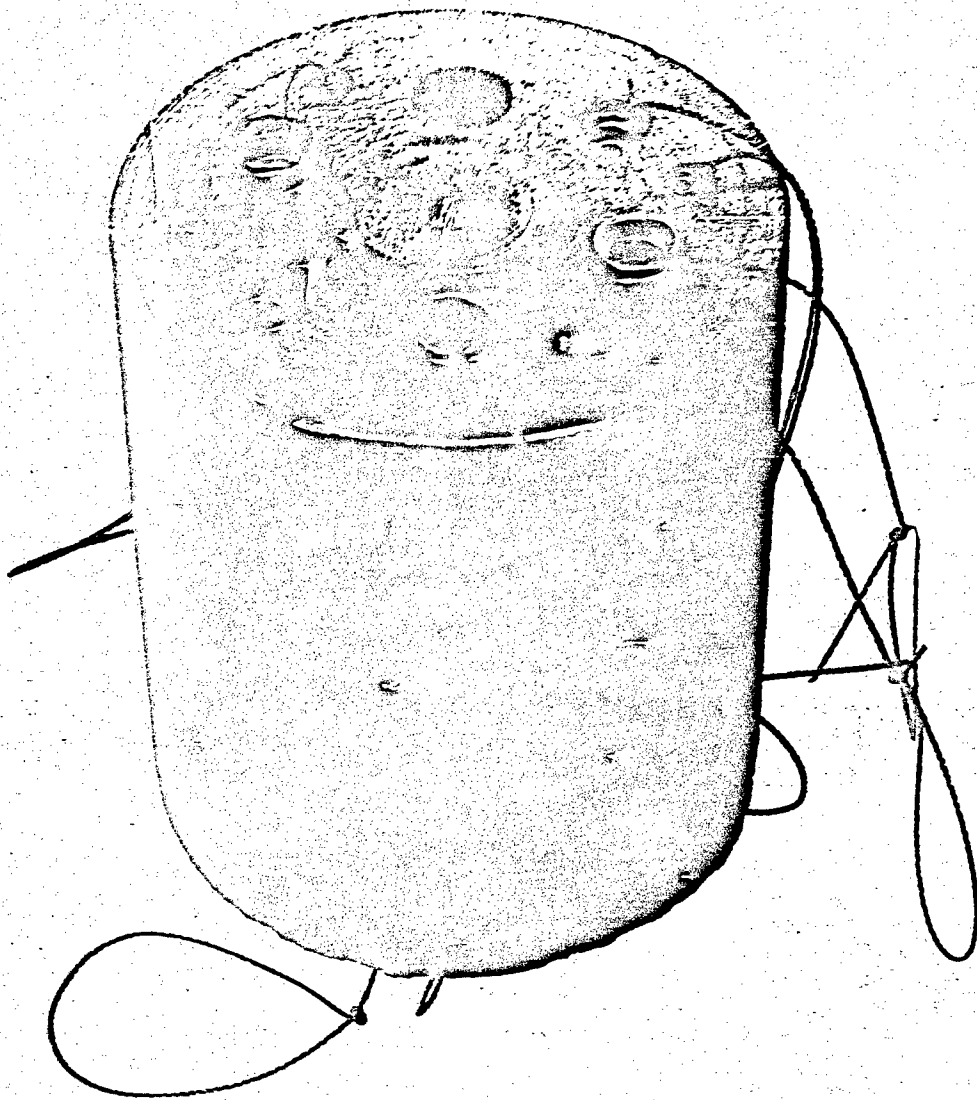
Tunnel ovens are generally used for monorail automated equipment. Either gas or infrared heating may be used. The monorail frequently is arranged to carry the coated parts back through the same oven or a second similar oven for reflow or cure. The use of two ovens is most advantageous in that this arrangement provides greater flexibility. In the case of thermosetting resins, a shorter cure at a high temperature will reduce the oven length and permit greater production rates.

Conveyorized lines may be set up to either convey the parts through the preheat oven to a hand dip station or be used in a fully automated manner. Fully automated operation is obtained by installing a fluidized bed unit with hydraulic lift, (Figure 3), between the preheat and post-heat ovens. When the monorail brings the work into position above the fluidizer, the hydraulic lift automatically lifts the bed and powder engulfs and coats the heated part. The hydraulic lift then lowers the bed and the part continues into the post-heat oven. Highly reproducible production coatings can be produced using this type of installation.

Induction heating can be used for preheating and curing but requires a considerable investment in electronic equipment and preformed coils for each configuration of part being coated. Induction heating is not readily adaptable to the irregularly shaped objects or those having great variation in cross section.

Fluidizer

If powdered coating material is placed in a container and an attempt is made to lower a part into the powder, it meets sufficient resistance to remain suspended on the surface of the powder. Contrast this with the condition produced wherein the powder is placed in a fluidizer and brought into a fluid state by compressed air. The powder floats on a column of air in a manner strikingly like a boiling liquid. Items immersed in the floating fluidized bed can be totally immersed and removed from the powder with very little resistance.



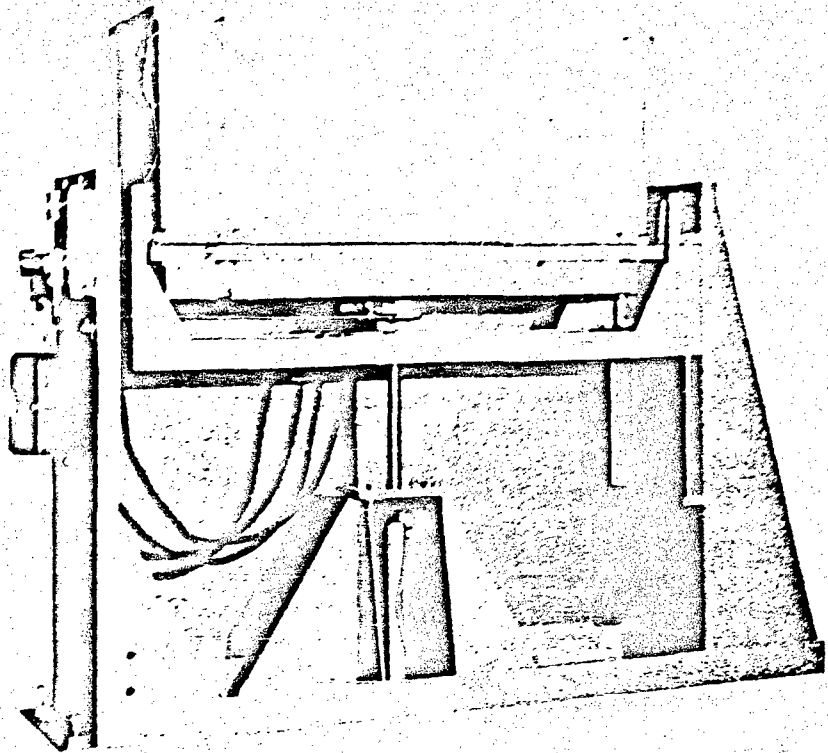
HEAT-SINK

FOR PREHEATING MISCELLANEOUS SMALL SPRINGS
PRIOR TO FLUIDIZED BED COATING

FIGURE 1

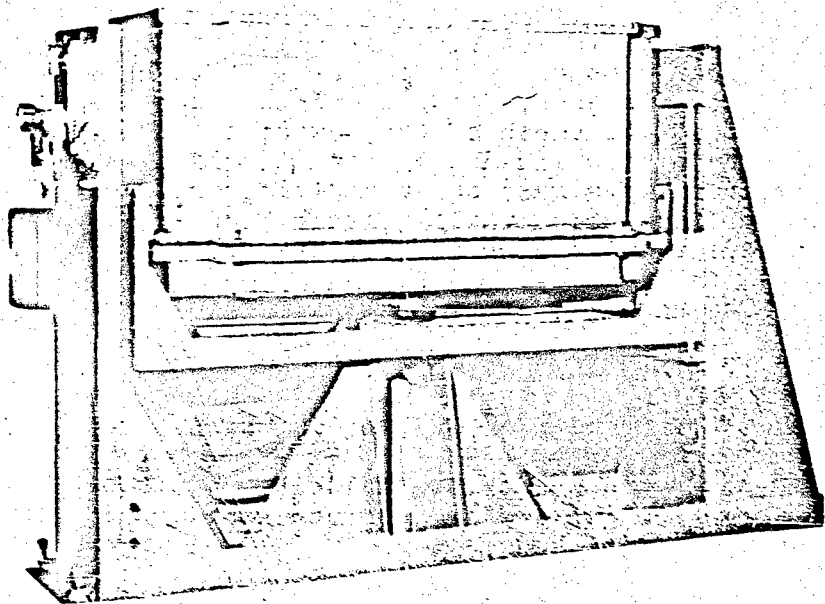
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Up Position

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Down Position

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AUTOMATED LIFT TANK

The simplest form of fluidizer consists of a container with a porous diaphragm a few inches off the bottom. Dry low pressure air is introduced into the plenum formed between the true bottom of container and the porous diaphragm. The ascending column of air passing through this porous diaphragm suspends the finely divided coating material which, in the fluidized state, acts, looks and even feels like a fluid and may splash and bubble like a boiling liquid.

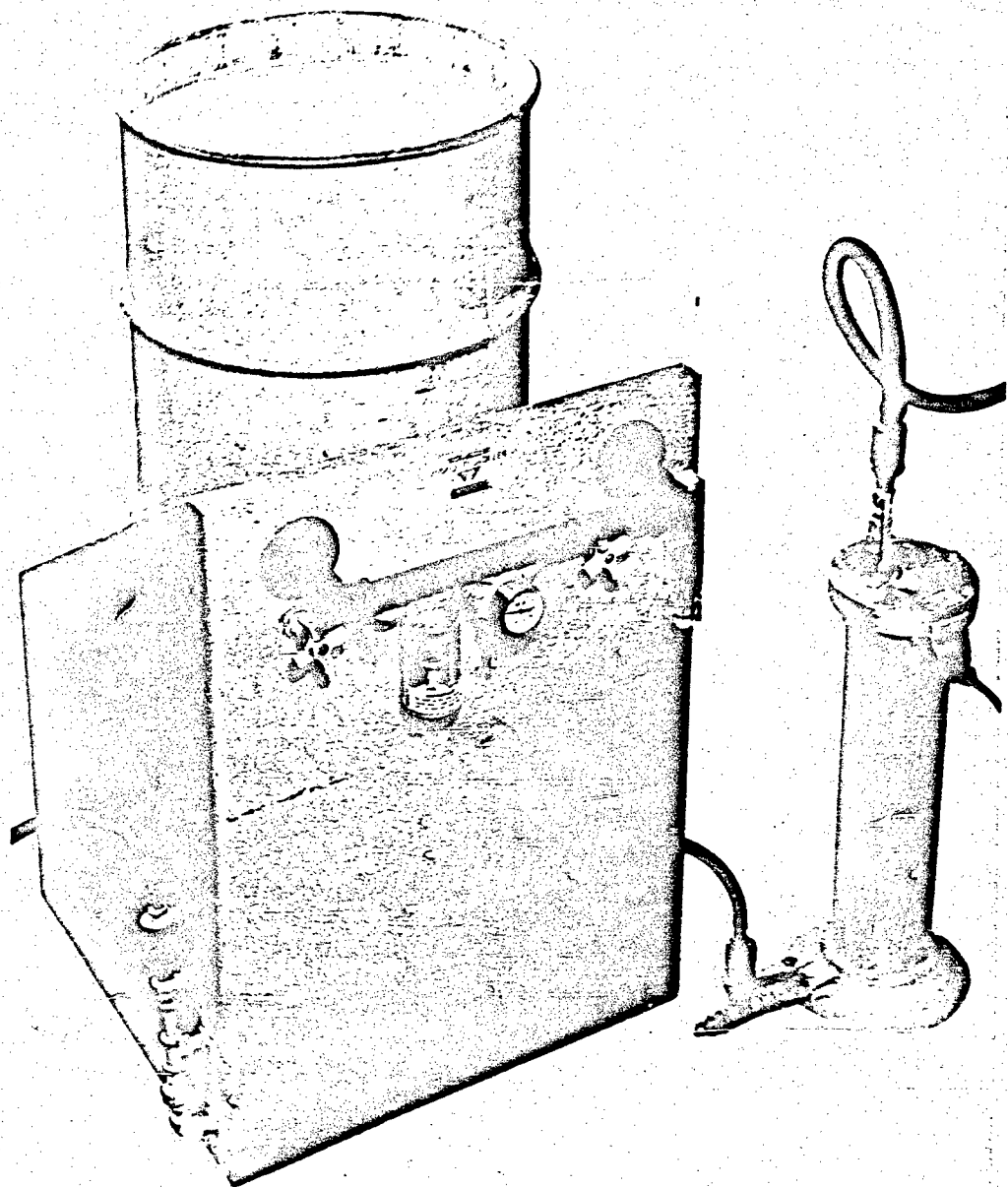
Like any boiling liquid, gas bubbles break through the surface and it is this bubbling action that tends to flip powder into the area air. It is this action that creates the dusting in the work area where the fluidizing is being carried out in simple fluidizers.

The bubbles rising through the bed also tend to produce nonuniform coatings on work surfaces they contact. The surface turbulence produced as they break, effectively prevents partial dipping a part to coat one area to a line while leaving the adjacent area uncoated.

In some commercially available equipment, (Figure 2), surface turbulence and dusting is virtually eliminated through the use of an orbital vibrator located on the bottom of the fluidizer. The entire bed is suspended on springs and the variable speed air driven vibrator is adjusted to a frequency needed to achieve this state varies from about 2500 cycles per minute to approximately 8000 cycles per minute. The exact frequency depends upon the density of plastic being fluidized, the depth of the powder in the unit, and the geometry of the fluidizing tank itself. In general, the high density powders such as polytetrafluoroethylene require the higher frequencies while polyethylene and other low density plastics requires low frequencies.

The use of vibrating beds produces several benefits:

1. The quiescent surface allows dipping to a line.
2. Virtually no dusting is encountered in the work area.
3. Freedom from channeling in the bed eliminates the need for the "to and fro" motion required for uniform coating in nonvibrating beds.
4. Less fluidizing air is required to maintain the coating material in a fluidized condition with vibration than without vibration. This reduces the heat transfer rate during coating and permits operation of the richer beds needed for producing thin coatings.



FLUIDIZER

TYPICAL EXPERIMENTAL SIZE VIBRATORY
TYPE FLUIDIZER WITH AIR DRIER

FIGURE 2

5. With vibration, it is possible to fluidize the high density plastics, metals, and pigment loaded coating compositions which have a pronounced tendency to dust excessively due to volcano like eruptions produced by severe channeling of the air in nonvibrating equipment.

6. Dead areas encountered in the nonvibrating beds are nonexistent in the vibrating type.

Materials of construction vary widely. Steel and aluminum are frequently used for both nonvibrating and vibrating type units. However, the use of metals in square or rectangular vibrating units must be carefully engineered to avoid fatigue failures in the metal and welds. For this reason, together with the fact that the metal walls may cancel out the beneficial vibration through resonance, some manufacturers have used resin bonded plywood tanks.

The heart of the fluidizer is the porous plate or diaphragm which distributes the air from the plenum into the chamber containing the powdered coating material. Many materials have been investigated for this purpose among which were multiple layers of kraft paper, sintered glass, sintered resins, sintered metals, hardware cloth, felt supported on wire, and many other materials. Recent development work by machine manufacturers has resulted in a superior type of plate consisting of a bonded cellulose fiber board. This material has sufficient rigidity and porosity to make large cross-section fluidizers possible. Even this superior material may fail if the fluidizing air carries substantial dust, oil and water which will reduce the porosity and eventually build-up sufficient plenum pressure to rupture the plate. This results in the coating material being suddenly and violently thrown from the tank.

A feature of most fluidizers is a protective expanded metal screen which protects the plate from being ruptured accidentally by dropping an object during coating operations.

Air supplies for fluidizing vary with the equipment manufacturer. The most flexible installation generally uses a compressed air source with suitable oil and dirt filters together with a desiccant-packed air drying tower. These dryers are commercially available with twin units electrically heated to rejuvenate the silica gel in one tube while the second unit is in use.

The importance of dry air can not be over-emphasized. Many of the thermo-setting resins currently applied contain acid anhydride curing agents which are converted by moisture

to the corresponding acid which is ineffective as a curing agent. For this reason, use of self contained centrifugal air pump supplies is undesirable. These units also inject dust and resin particles into the plenum unless fitted with a filter which drastically reduces their efficiency.

The size of a fluidizer may be varied considerably from a quart size unit to one many feet in length and depth. A shallow depth bed may be increased in depth at will merely by attaching additional panels to the front, back and sides of an existing unit. It must be borne in mind that the limit is not one of unit cost or mechanical limitations, but one related to the investment required to fill the unit with the powdered resin to be used.

An equally important consideration relating to size of the unit is the problem of coating color, type of resin, and chemical properties desired. For instance, in a shop when a large unit is in use, a black resin may be in current use. A sudden need may arise for the application of a white, pink, powder blue, another light colored coating or even a different plastic. Changing from one color or material to another requires meticulous cleaning to insure that none of the previously used material remains. For this reason, it is most often advisable to construct additional tanks for each color to be stocked. The bed itself, when equipped with a tight fitting lid, serves as a storage container. For this reason, the size of a unit should be as small as will accomodate the parts to be coated and maintain the anticipated work load.

It is frequently found that a series of various size fluidizers is more desirable than one large unit. This is specifically true where the coated part sizes vary considerably and the types or color of coating material are quite diverse. Coating material inventories required will be reduced by using only the amount of resin required to fill the smallest unit which will accomodate the part being coated.

Cleanliness is a prime consideration where fluidized bed coatings are applied and all units must have tight fitting covers which will exclude dust, lint and moisture. Dirt entering the fluidizer is codeposited on the work surface where it remains as a defect in the coated surface.

ESSENTIAL CHARACTERISTICS FOR THE COATING MATERIAL

A powdered plastic designed for application by the Fluidized Bed Coating Process must have certain characteristics to be useable as a coating material.

1. The char point of the resin must be sufficiently above its melting temperature to allow the part being coated to be heated to a temperature sufficiently higher than the melting temperature to produce fusion of the coating without charring. The greater the difference between these temperatures the more desirable the material for the fluidized bed coating process.

2. The coating material must be suitably compounded to avoid the tendency of most organic materials to draw back from edges and corners. Certain thixotropic agents and flow control agents which minimize this tendency must be added by the formulator.

3. Many organic pigments are destroyed by the temperatures reached by the plastic material applied to the work surface. Therefore, it is essential that color pigmentation be of the heat stable or ground inorganic frit types.

4. Particle size is of considerable importance in obtaining the thinner coatings. It is equally important to avoid levitational classification of the bed in use. The percentage of larger particles gradually increases as the smaller particles are used in the coating action near the top of the bed. Special coarse particle powders are supplied for use in nonvibration type fluidizers to avoid dusting. The larger the particle size the heavier the minimum thickness which may be applied.

5. In phenolic, epoxy and other thermo-setting resin powders, the use of curing agents which have good shelf life and low moisture sensitivity are a necessity. Resins must be storable for months at room temperature if the process is to compete with the usual solvent systems.

6. The powdered coating material must have a sintering temperature high enough to preclude blocking in shipment or storage but low enough to provide good flow characteristics at the application temperatures.

Selection of Coating Material

Many considerations should enter into the selection of the coating material to be used. First the decision must be made as to what functional purpose is to be served by the coating. Is it to be primarily decorative, functional, or both decorative and functional.

Decorative Applications

Some plastic materials have inherently better gloss than others. For instance, among the higher gloss materials applicable by the Fluidized Bed Coating Process is cellulose acetate butyrate. This material has an extremely high gloss when properly applied and is sufficiently colorless to be capable of being pigmented with the lighter pastel colors. In contrast with this, the fluidized bed applied epoxy materials have somewhat less gloss than that of the cellulose acetate butyrate type. In addition, the inherent yellow color of the basic epoxy resin limits the range of colors and makes it impossible to achieve a true white and many of the more delicate pastel shades. Vinyl compositions frequently used for decorative purposes have an advantage of being obtainable in a range of coatings ranging from very soft to hard in most colors.

While most coating materials can be pigmented to produce attractive colors and textures, one of the important properties not to be overlooked is whether the part to be coated is capable of withstanding the preheat and post-heat temperatures needed for the type of coating to be applied. Table I indicates the range of application temperatures for many of the plastic coatings applicable by the fluidized bed technique.

TABLE I

Metal Preheat Temperatures (°F) Required For Fluidized Bed Coatings

Epoxy Resins	250 to 450
Polyvinylchloride	375 to 550
Polyethylene	300 to 600
Cellulose Acetate Butyrate	500 to 600
Chlorinated Polyether (Peaton)	500 to 650
Polypropylene	500 to 700
Polyamide (Nylon)	650 to 800
Polytetrafluoroethylene (Teflon)	800 to 1000

It will be noted that except for the epoxy and low range polyethylene and vinyl coatings, the application temperatures of the plastics listed are above the draw temperature of carbon steels and well within the melting range of the soft solders. In the case of aluminum and magnesium alloys, even the epoxy, polyethylene and vinyl materials are applied at temperatures which will adversely affect the T6 tempered alloys. However, the designer working with the metallurgist can shorten the artificial aging treatment by an amount equivalent to the time the metal is at temperature during the preheat and postcure (or reflow) portions of the coating process, and adverse effect will be avoided.

One of the most important considerations in the selection of a plastic material to be applied either for a decorative or other functional use is the problem of adhesion. Primers are needed under many of the coating materials, (see Table II). Application of the primers by the solvent system immediately detracts from the advantages gained by adopting the fluidized bed coating technique.

TABLE II

	<u>Primer</u>
Epoxy	No
Polyvinylchloride	Yes
Cellulose Acetate Butyrate	Yes
Polyamide (Nylon 11)	Yes
Polyethylene	No
Polypropylene	Yes
Chlorinated Polyether (Penton)	Yes
Polytetrafluoroethylene (Teflon)	No

Several disadvantages are encountered in the primer application area. First the primers used must be specially formulated to withstand the preheat temperatures which they encounter immediately prior to application of the fluidized plastic material. The material applied must be thoroughly dried prior to preheating or bubbles and nonadherent areas will be encountered at points where the remaining is rapidly driven off in the high temperature preheat oven. This

problem usually leads to such additional precautions as de-tearing and/or a low temperature baking prior to the part entering the preheat oven. Secondly, if facilities for handling the spray or dip application of the primer must be established, it is frequently felt that the use of conventional sprayable coatings would be less costly and more easily accomplished.

In the case of the vinyl materials, an interesting technique of fluidized bed priming and finish coating has been developed. The cleaned part is preheated to approximately 400°F and coated in the epoxy fluidized bed and while the epoxy is still in the sticky ungelled state, the part is immediately dipped into an adjacent bed of fluidized vinyl coating material. The "sugar coated" part is then transferred to a 500°F oven for five minutes to simultaneously cure the epoxy and reflow the vinyl top coat.

Nylon is worthy of comment at this point in regard to priming. In many applications where the nylon is not to be used in contact with water or more particularly is not to be hot water washed or sterilized, no primer is necessary. The high water vapor permeability and water absorption characteristics of nylon are frequently used as a means for stripping unprimed nylon coatings. The parts to be stripped are submerged in a tank of boiling water and allowed to remain for a period of time sufficient to cause the coating to separate from the basis metal. The coating is then slit with a knife while still hot and is then easily peeled from the surface. Primed nylon will not hot water strip.

Special Decorative Effects

The range of decorative effects in fluidized bed applied coatings is virtually unlimited. In the case of vinyl coatings, powders are available in which a solid base colored material is pigmented with a higher melting point polymer of a different color. Three or even a greater number of different colored materials can be added to produce "salt and pepper" or other pleasing effects.

Heat embossed patterns, grains, and textured surfaces can be obtained by well known hot embossing techniques. Matte or lusterless coatings may be obtained by treating the surface with suitable solvents.

Other decorative uses involve the application of various colors to different areas either through the use of masks or overlapping of two or more colors applied to opposite ends of an item.

Use of a flocking gun to apply a streak or pattern of one color over another solid base color coat can be employed to obtain special effects.

Two-colored nameplates, decorative engravings or instrument dials can be prepared by coating the object with first a layer of colored epoxy followed by a second coat of another color. Engraving through the top coat to expose the first applied layer produces an attractive nameplate, dial or engraving.

In using the epoxy resins, a heavy coating can be applied to a metal base, the coating engraved and a second color applied. The entire surface is then ground down to the surface of the first color applied leaving the second color only in the engraved areas. The epoxy resin is generally preferred in this case because of its machinability and its superb adhesion both to the basis metal and to previously applied layers without need for primers.

ENGINEERING APPLICATIONS OF FLUIDIZED BED COATINGS

The fluidized bed coating process may be considered to be in its infancy. However, the engineering applications are already so numerous that only a few of the most interesting can be covered.

When discussing the field of coatings one of the first considerations entering the mind is how effective is the coating in preventing corrosion. The answer to this question is, in the case of fluidized bed coatings, more ambiguous than those obtained when the same questions are asked concerning various types of paint. Inasmuch as this is an important subject, some of the variables involved would merit some discussion.

Corrosion Prevention

Paints, enamels and lacquers often employ the same plastic or resin systems applied by the fluidized bed coating process. The water vapor transmission rate of their dried films is a function of the resins employed, the pigments used and in the case of paint-like systems the microporosity imparted by the evaporating solvents.

The fluidized bed coating process involves the loss of no solvents. Fusion of the coating during application leaves the coating nearly pore free. Therefore, only the pigment system and the type of resin itself determines the water

vapor transmission rate. The greater thickness of coating applied enhances the protective properties by providing a thicker barrier.

Possible causes for local corrosion failures exist where dirt, lint or other contaminants are allowed to enter the fluidized bed where they are codeposited with the plastic on the metal surface. These contaminants, depending upon the nature, may act as a wick or flaw through which the corrodant can penetrate part or all of the thickness of the coating. Presence of dirt can be detected readily with a high voltage spark tester which locates the lower dielectric areas where the effective thickness is reduced by the presence of dirt.

Many applications to prevent corrosion have been made using most of the available plastics. Cellulose acetate butyrate has been applied to pole transformer covers for several years. Several cases were observed where condensation and corrosion inside the cover (which had not been coated) had almost completely destroyed the metal, leaving the coating intact.

Stainless steel sono-buoys dropped in miles deep sea water corrode rapidly due to absence of sufficient oxygen to maintain a passive condition. Coated with fluidized epoxy the metal remains corrosion free after months of immersion.

It may be seen from the above that both the epoxy and cellulose types of coatings will provide protection of metals under conditions of severe service where ordinary coatings and corrosion resistant metals prove to be unsatisfactory. Vinyl, chlorinated polyether, polyethylene and polypropylene will function as well or better than either the epoxy or cellulose acetate butyrate in specific applications depending upon the environment to be encountered in use and the other physical demands imposed upon the coating in service.

Ultraviolet resistance is of considerable importance if gloss is to be retained after prolonged exposure to sunlight. Thus, the slight (but self arresting) chalking of epoxy type coatings may prove to be objectionable in such applications. The excellent gloss retention by the cellulose acetate butyrate under identical circumstances would make its use more desirable.

In an alkaline media such as would be encountered in chemical service applications or even the slightly milder alkaline environment of an automatic washer tub would make the cellulose acetate butyrate less desirable in these applications than the chlorinated polyether, vinyl, epoxy, polyethylene or nylon.

While vinyl coatings prove to be excellent for use in contact with oxidizing acids such as chromic acid encountered in chromium plating, the epoxies, nylon and cellulose acetate butyrate are not satisfactory. In a more severe application such as service in handling oxidizing acids such as 50% nitric acid at room temperature only chlorinated polyether coatings prove to be satisfactory.

It should be evident from the above that selection of a coating material for prevention of corrosion or for chemical service is dependent upon the corrodant to be encountered. The selection is further complicated by the temperature to be encountered. The maximum service temperature for each type of coating is a function of the polymer, the pigments and the modifiers used. Table III shows the maximum service temperatures for the various coating materials compared to the application temperature range for each. These maximum service temperature figures shown may vary considerably. For instance, one producer of epoxy fluidized bed powder specifically designed for electrical properties contains nearly 50% of ground dolomite limestone which acts as support where hot wires would ordinarily cut through the coating.

TABLE III

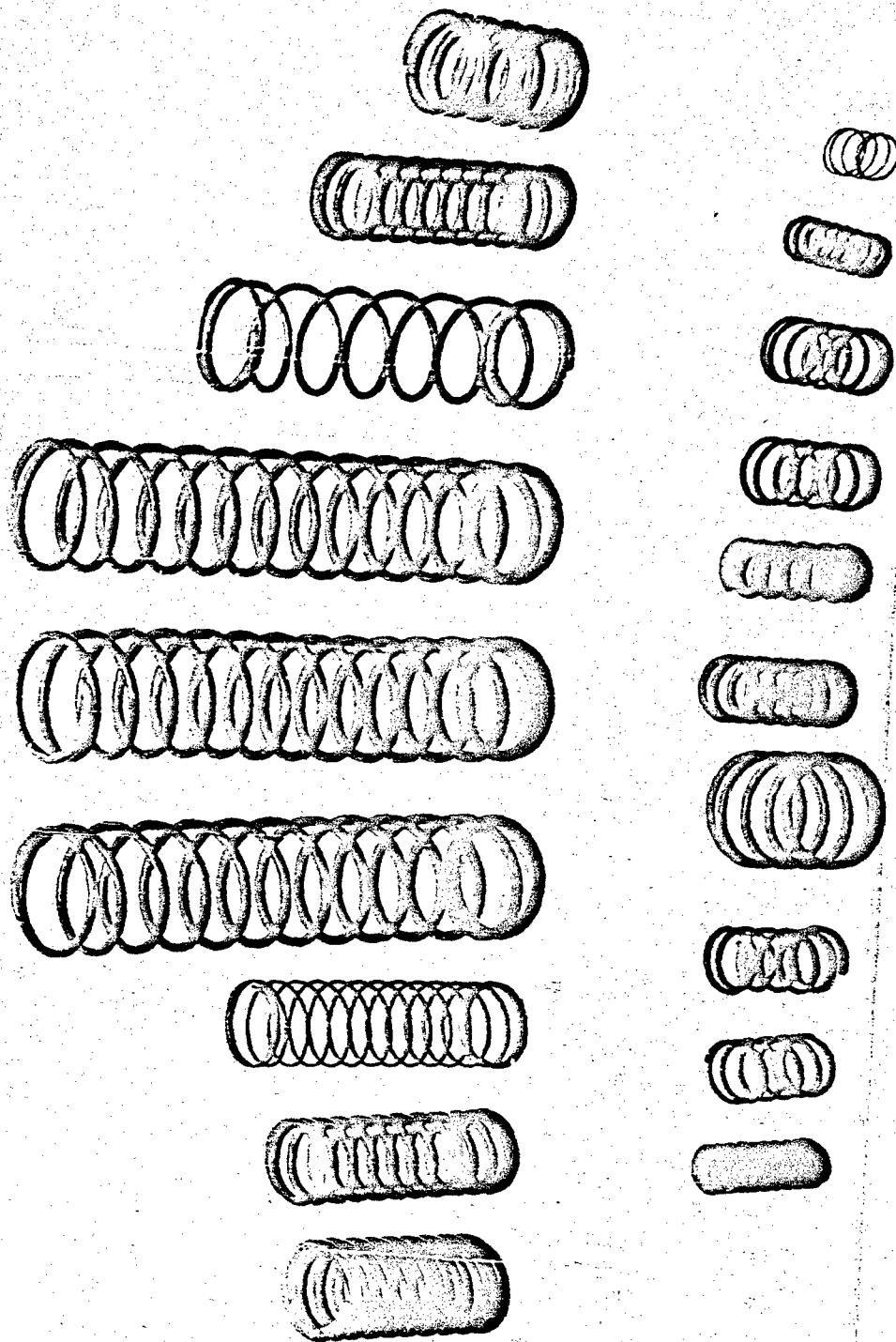
<u>Coating Material</u>	<u>Maximum Service Temp. °F</u>	<u>Application Temperature Range</u>
Epoxy	350	250 to 450
Poly Vinyl Chloride	200	375 to 550
Cellulose Acetate Butyrate	160-180	500 to 600
Polyamide (Nylon)	180	650 to 800
Polyethylene	160	300 to 600
Polypropylene	Varies with molecular weight	500 to 700
Chlorinated Polyether (Penton)	250-280	500 to 650
Polytetrafluoroethylene (Teflon)	390	800 to 1000

Thus properties of such coatings may be altered to produce certain desired qualities. A coating specifically altered as described above will exhibit poorer corrosion resistance than the less highly pigmented types. It is therefore impossible to make general statements concerning the corrosion resistance of a specific type of plastic coating. Careful selection of the corrosion preventive coating followed by actual environmental tests of several products of the particular type will provide the best evaluation of performance. Water immersion, salt spray tests and other accelerated tests require extremely long test periods to produce even the slightest coating breakdown. It is not uncommon for cellulose acetate butyrate to withstand 6500 hours exposure to the salt spray without evidence of corrosion or degradation of the coating. Epoxy coated mild steel panels immersed in aerated distilled water for one year remain entirely rust free with no visible alteration of gloss or color. It is difficult to predict the many excellent applications where the use of fluidized bed coated components will provide long time cures for corrosion problems of long standing.

Hydrogen Embrittlement

Hydrogen embrittlement is one of the most serious problems encountered in the use of plated springs. Catastrophic failures of vital plated springs and high strength steels has brought about a frenzied search for new non-embrittling spring plating and coating processes. Catastrophic failure due to hydrogen embrittlement of such items can be virtually eliminated through the application of epoxy fluidized bed coatings. Figure 4 shows a group of typical epoxy coated springs. Consideration must be given the fact that the solid height of the spring will be increased by an amount equal to twice the thickness of coating applied, times the number of turns in the spring. Tests conducted at -65°F show no cracking or chipping of the coating when typical springs were flexed 1000 times to within ten thousandths of their solid height. Excellent resistance to corrosion, oils, greases and most vapors make the coating more desirable than the usual plated springs in many applications.

One of the benefits derived from the use of epoxy coatings on springs is the absolute assurance provided by the preheat and cure cycle that the spring has been properly stress relieved after winding. This is a very important consideration in spring making. Unless stress relief is carried out immediately after winding, fine transverse peripheral cracks may form in the high fiber stress surface. These cracks act as stress raisers which constitute the point of failure of such springs in service use. The coating process



TYPICAL PRE-STRESSED WOUND WIRE SPRINGS
WITH FLUIDIZED BED APPLIED COATINGS

FIGURE 4

can be integrated with the normal stress relief by applying the coating during the stress relief period or as the springs are taken from the stress relief oven. With no exposure to cleaning solutions, acids or plating operations hydrogen embrittlement failures will not be encountered. Corrosion resistance and excellent abrasion resistance of the epoxy coatings insure long time protection against corrosion and failure.

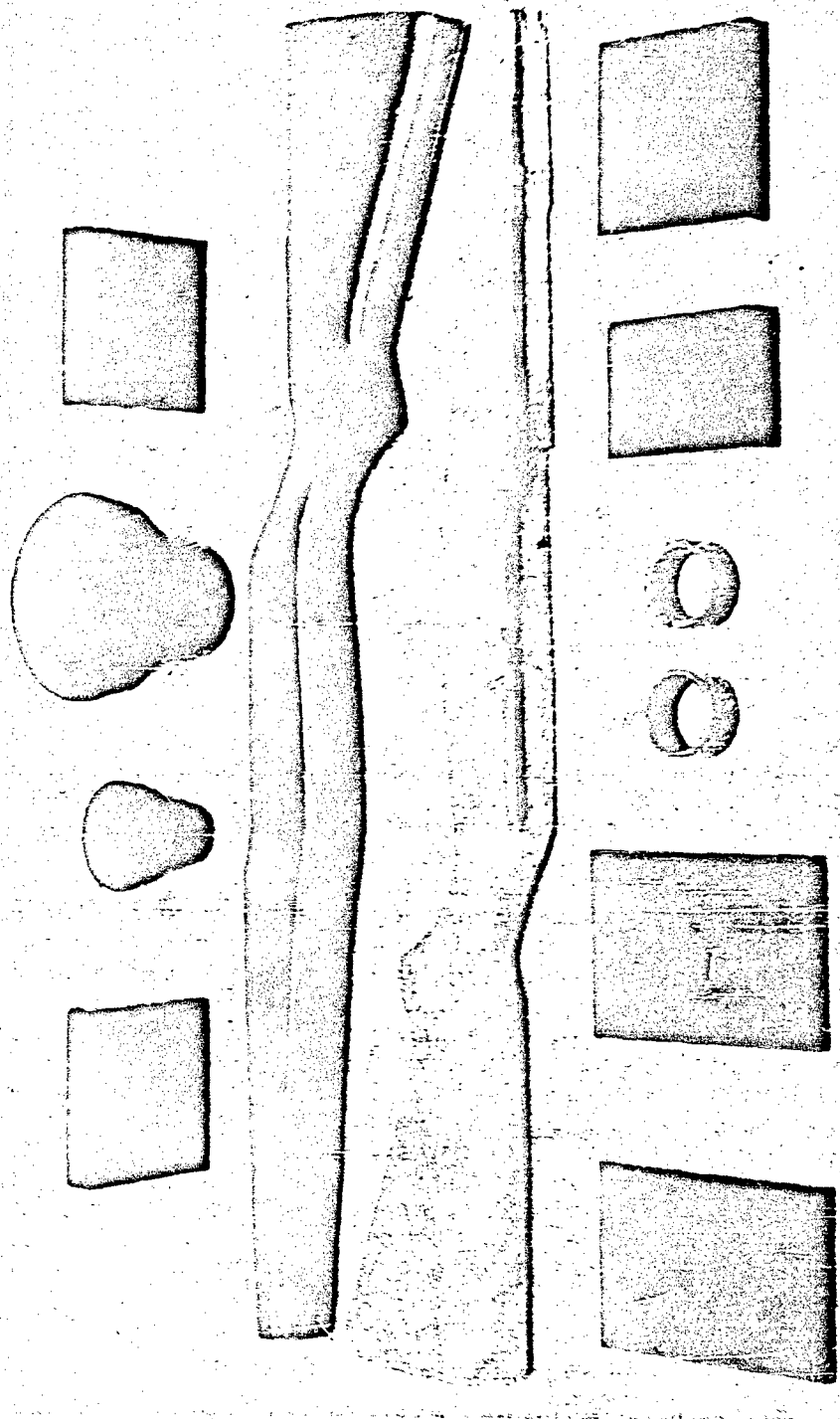
Coating of Porous Structures

One of the most unique and useful properties of fluidized bed coatings is the ease of application of the coating to porous structures not easily coated by other means. Sintered metal parts, wooden objects, transformer coils, clay or ceramic parts, graphite and porous metal coatings can be simultaneously impregnated and coated by this process. Success will depend upon the skill of the operator in selecting the proper preheating, dipping and cure temperatures.

Consider for one moment the conditions existing within a single pore in a solid object capable of withstanding short time heating to 400-500°F. As the part is heated to the desired dipping temperature, air within the pore expands and a portion of this air is driven out due to its increased volume. If the heated part is then taken from the oven, and held momentarily in the air, immediate cooling causes a contraction or decrease in volume of the air within the pore. If the part, (which at this point should still be within the range of dipping temperatures) is then immersed in the fluidized bed, a coating will form. While the fused coating is still liquid, it will be drawn into the pore as the part cools further. If the coated part is then placed in a curing oven at a temperature slightly below the temperature of the preheat oven, the coating will cure free of bubbles and pores. Care must be exercised when coating wood, graphite, and sintered metal parts to insure that the preheat period is sufficiently long and slightly higher than the actual desired dipping temperature to drive off any volatile, oils, gases, etc. prior to dipping. Figure 5 shows a group of epoxy coated porous materials ranging from a clay flower pot to a wooden (Birch) gun stock, a graphite block, to yellow pine plywood panels. The delay before dipping and the slightly lowered cure temperature employed are the most important considerations involved.

Hydraulic Cylinders

Due to the excellent resistance of the epoxy coating materials to petroleum hydraulic fluids and the excellent adhesion and machinability of these coatings, their use as liners



POROUS OBJECTS COATED WITH FLUIDIZED BED

FIGURE 5

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for hydraulic cylinders has been investigated. The rough honed cylinder is coated internally with an epoxy coating 0.020 to .030 inches thick. The properly coated and cured cylinder is then rotary honed to the final dimension, draw polished and assembled. Excellent finishes of less than ten microinches can be obtained after honing and polishing. The resulting completely epoxy lined cylinder is corrosion proof and easily repaired. Merely cleaning and redipping the cylinder will make it possible to rehone and polish the cylinder, thus returning it to service in as-good-as new condition.

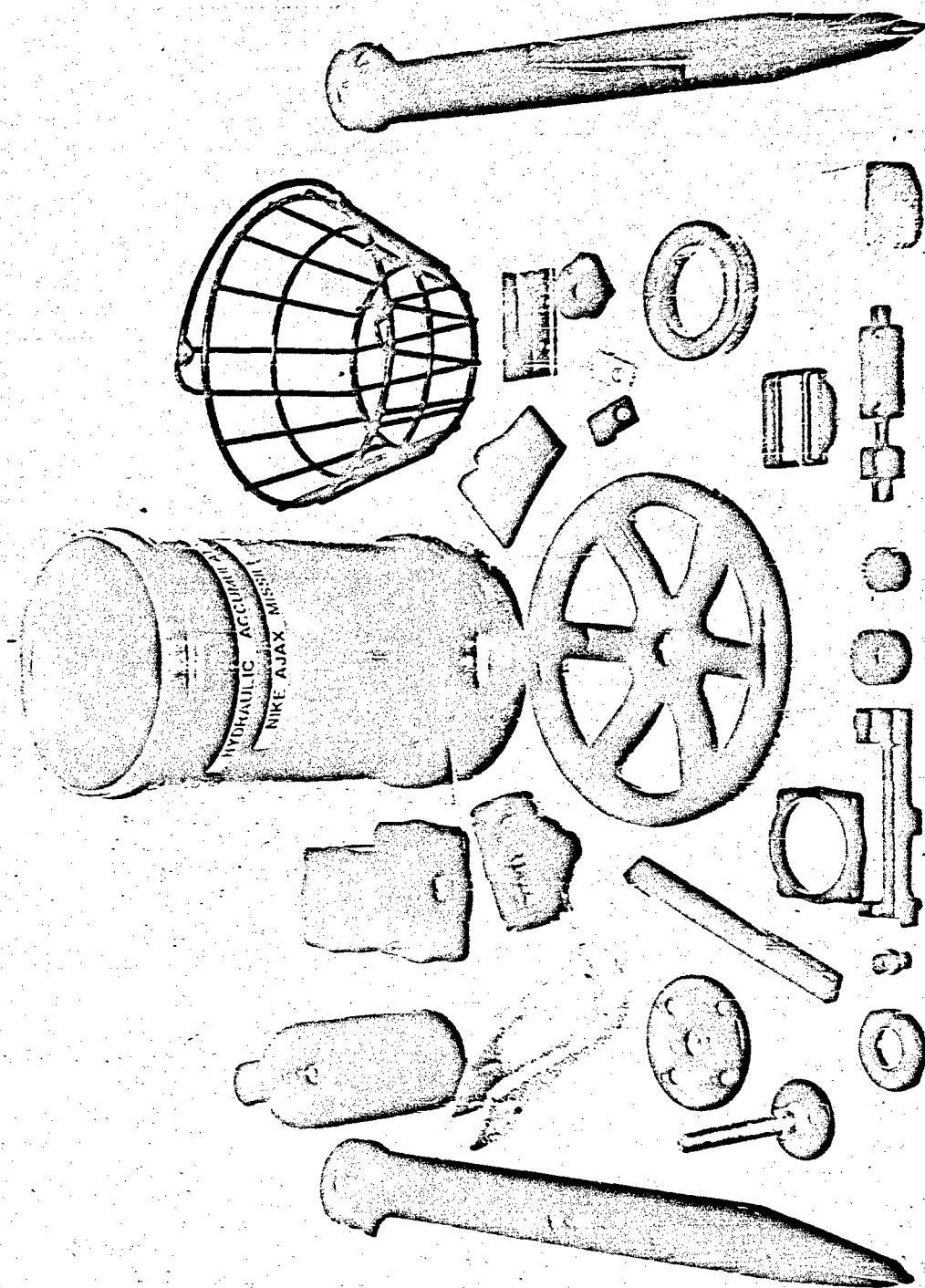
A similar technique may be used to reclaim corrosion pitted or scratched cylinders.

A slightly modified version involves cleaning and coating the pitted or scratched cylinder without removal of any metal. The cylinder is then rehoned to the original dimension. This treatment results in complete filling of all pits and scratches without leaving a lining of plastic within the cylinder. Tests of this method indicate that the coating can be honed to a feather edge without chipping or other indication of adhesion loss. The above are applicable to hydraulic piston rods where the coating will serve to prevent corrosion at the critical area of contact with the packings. Thus, completely epoxy coated hydraulic systems unaffected by water and other corrodants are possible. Shown in Figure 6 is an experimental hydraulic accumulator coated internally with epoxy resin.

Shown to the left of this cylinder is an experimental wheel brake cylinder usable only with petroleum base or diester type brake fluids. Most polar type fluids used in modern automotive applications will soften the epoxy coating and result in failure. Immersion tests should be conducted when any proprietary hydraulic fluid of unknown composition is used.

Bearing and Wear Applications

One of the many promising applications for fluidized bed type coatings is in the production of friction reducing (lubricative) coatings. The excellent frictional qualities of polyamide (Nylon) coatings have been used in bearing applications for a number of years but such problems as dimensional change due to moisture absorption and poor bearing retention due to these changes has prevented more widespread use. Bearings can be produced by fluidized bed application of polyamide (nylon) either in its usual form or pigmented with friction reducing molybdenum disulfide.



MISCELLANEOUS EPOXY RESIN COATED ITEMS

FIGURE 6

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Bearing retention problems are virtually eliminated if the metal surface to be used as the bearing support is roughened by abrasive blasting or knurling prior to priming and application of the fluidized coating. Coatings applied directly to the basis metal have apparent good adhesion when first applied, but after a period of storage or use, the coating will delaminate due to dimensional changes caused by adsorbed moisture from the atmosphere. Therefore, where polyamide coatings are applied for bearing properties, the basis metal must be prime coated prior to coating with the nylon.

Polyamide (nylon) coatings are quite sensitive to both oxidation and thermal degradation at the temperatures encountered in their fluidized bed application. This degradation causes brittleness and cracking under load. It is therefore of some importance to minimize these thermal and oxidative effects by such measures as using nitrogen gas instead of air for fluidizing the powder and employing a nitrogen atmosphere in the reflow oven. Rapid cooling after reflow either by water quenching or in a water spray will help to avoid oxidation during cooling. Grinding or other machining to the final dimension will remove the slight amount of surface oxidation which may be encountered in spite of the precautions suggested.

The thin polyamide coatings which may be applied by the fluidized bed process exhibit distinct advantages over machined massive types. Direct bonding of the coating to the basis metal insures bearing retention and more readily, dissipates the frictional heat to the metal base.

There are many successful bearing applications of polyamide fluidized bed coatings. Possibly one of the largest is their use on ball joint suspensions for automotive use.

Coated metal gears provide silent operation where the properties of excellent scuff and wear resistance are needed in locations providing little or no lubrication.

Polyamide fluidized bed coated pillow-block bearings used in evaporative cooler fans outlast several sets of standard bearings. In this particular operation, both the corrosion prevention and lubricative properties required are obtained by application of a .010 inch coating.

One of the principle problems in the application of polyamide coatings is the high preheat temperatures (650°-800°F). This requires careful selection of the metals, alloys and heat-treatment to avoid adverse effects. Heat treated carbon

steels, aluminum and magnesium must be avoided if physical properties are vital.

A second problem of considerable importance is the service temperature in the area where the coating is used. The service temperature may reach approximately 350°F for short periods of time without distortion, however, prolonged exposure to temperatures above 180°F will embrittle the coating and result in failure.

While tetrafluoroethylene (Teflon) coatings exhibit a characteristic unctuous surface resembling soap, the softness of the coating and the fact that these coatings fail to lubricate at high surface speeds tends to reduce the attractiveness of the coatings for many bearing applications. Limited application may be made in isolated instances where a particularly corrosive atmosphere exists and both bearing loads and contact surface speeds are relatively low.

The vinyls, polyethylene and cellulose acetate butyrate exhibit poor bearing qualities and are therefore not used where load bearing properties are required.

Epoxy coatings, which may be applied at temperatures as low as 240°F have the advantage of not adversely affecting the heat treatment of carbon steel, aluminum or magnesium and have excellent adhesion to most metals without need for the use of a primer. The coatings are hard, chip resistant, machineable and may be pigmented with dry film lubricants. Coatings having up to 35 percent molybdenum disulfide dry lubricant are easily applied in thicknesses up to .050 inch in a single dip. The resulting film is of sufficient thickness to provide a long lasting self lubricating bearing surface.

Paint type dry film lubricants in contrast must be applied by laying down a multiple coat system to obtain even a nominal thickness of .001 inch.

Bearing surfaces may be operated in contact with water and most oils without adverse effect.

The excellent performance of epoxy coatings under compressive loads has led to their use in sliding detent applications, on latches and on ball and socket joints such as ball-hitches.

The use of epoxy resin coatings for hydraulic cylinders and hydraulic piston rods has been discussed above.

In a study conducted by Blessin⁽¹⁾, coefficient of friction measurements were made on both polyamide and epoxy coatings within a temperature range of -65 to 160°F and at a surface speed of five feet per second under 600 pounds per square inch load. The polyamide coating showed negligible wear, with friction coefficients of from .13 to .26. Epoxy coatings under the same conditions showed slight wear grooves at 160°F and were found to have friction coefficients between .03 and .47. The addition of ten percent by weight of flake graphite increased the friction coefficient to .38 to .50. No explanation for the increase was offered.

Attractively low wear rates and frictions were obtained with epoxy working against epoxy at -65°F and epoxy against anodized aluminum at 80°F. The average frictions for epoxy coatings were slightly higher than for the polyamide coatings, though not significantly so. While wear grooves of .003 inch deep were observed in the epoxy coating at 160°F, this represents very good durability. The future extensive use of fluidized bed epoxy coatings with added molybdenum disulfide is assured in view of the application temperatures required for the polyamide coatings.

Electrical Insulation Applications

One of the most extensive fields of utilization of fluidized bed coatings is in the application of insulative coatings. Each of the materials listed in Table I have been employed in one electrical application or another. The various desirable properties of each type of coating must be carefully balanced against the possible requirements for the specific application and the inherent undesirable characteristics before a choice of the type of coating is made.

In addition to superior electrical products made possible through the use of fluidized bed applied insulation, a considerable saving in labor has been realized in the production of many of these electrical products. For instance, in the production of electrical motors the cost of slot liners, end fibers and other insulation is saved, together with the cost of their placement. The percent of rejected motors due to insulation difficulties is drastically reduced.

(1) Blessin, F., "Friction and Wear Properties of Plastic Coatings Applied By The Fluidized Bed Process", Rock Island Arsenal Report No. 61-3143, 24 August 1961.

The epoxy fluidized bed coatings used for electrical applications are specially compounded epoxy resins with thixotropic agents which enhance edge and corner coverage. Edge and corner coverage is high as 60 to 70 percent of the flat wall thickness is possible. This allows the magnet wire to be wrapped more tightly with sharper bonds and reduce the space required for the return bends. A saving in weight is also realized in shorter windings and reduced case size.

A combination decorative and functional application of epoxy coatings has been made by several manufacturers of hand power tools who coat the cast aluminum housings for the tools. An attractive smooth coating is obtained and the problem of shock hazard is almost completely eliminated. An added advantage of the application is the elimination of almost all the cost of hand finishing of the rough casting. Porosity of the casting is no longer a problem and lower grade castings may be used without sacrifice in either appearance or functioning of the tool.

Encapsulation of transformers and other similar cored equipment may prove to be difficult to accomplish in production unless the component is specifically designed to eliminate some of the problems. Among the most frequent causes of trouble in encapsulation of standard commercial transformers is the difficulty caused by the release of gases by interleaving insulation, coil wrappers, and oil on laminations. When heated to the temperatures required for application and curing of the coating, even the air between coil strands expands and will create bubbles in the coating unless the coil is preheated to a temperature higher than the dipping temperature and dipped only after a short cooling period to allow the gases to contract. The cure temperature used under these circumstances should be established at approximately the temperature of the part after dipping. Cure time will be dependent upon this temperature.

Where the above precautions are carefully exercised, satisfactory encapsulation of commercial transformers can be accomplished with an acceptable level of rejections. The most desirable condition is one in which the transformers is specially designed to favor the use of fluidized epoxy encapsulation. An example of the recommended procedure and design for epoxy encapsulation is as follows:

1. Using a fiber glass-epoxy coil core and removable silicone rubber winding grommets, random wind the coil using epoxy cement coated wire.

2. Fuse the cement coated wire coils in an oven and allow to cool for removal of the winding grommets.

3. Cut the core to the desired length to separate individual coils and attach properly etched "Teflon" insulated primary and secondary leads.

4. Trichloroethylene vapor degrease laminations and assemble with the fused coils.

5. Secure primary and secondary leads to clip on laminations.

6. Heat entire assembly to 425°F, partially cool as recommended when coating porous materials and dip into the fluidized epoxy powder to produce the desired coating thickness.

7. The transformer should then be placed in a 400°F curing oven for one-half hour to cure the coating.

If desired, the coils may be assembled on the armature and epoxy coated directly from the oven used to fuse the cement coated coil.

The product resulting from the above procedures are smaller, waterproof and capable of sustaining greater overloads than transformers insulated in the conventional manner.

The subject of insulation by epoxy coatings is one deserving some additional discussion. The published dielectric properties of the coatings vary widely between suppliers of the resins. These variations presumably reflect differences in the methods of testing, the thickness and integrity of the coating, composition and pigmentation of the resin as well as the duration of the test and moisture content of the air in which the coating was conditioned. A typical list of short time dielectric strengths are shown in Table IV.

While the values shown vary considerably as noted in the previous discussion, they can be maintained in production application of coatings through selection of the coating materials, application techniques and thickness. It can readily be seen that high voltage insulation of bus bars and other conductors by the fluidized bed coating technique offers attractive advantages over the tape wrapped or vinyl plastic dip types of insulation. The dielectric properties of fluidized coatings applied can be tailored to meet any requirements specified by merely selecting and apply a coating.

TABLE IV

Short Time Dielectric Strength
of Fluidized Bed Coatings

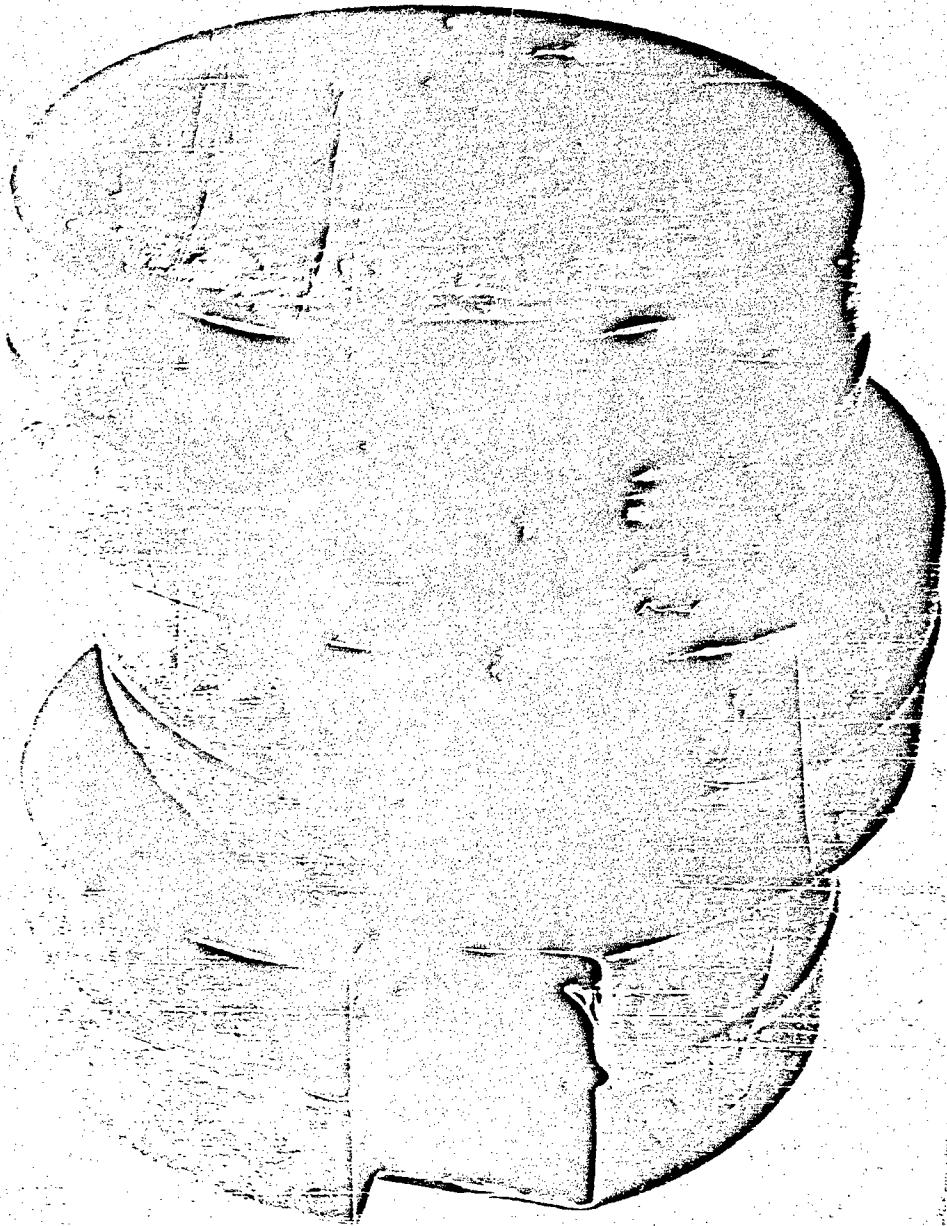
<u>Coating Material</u>	<u>Thickness</u>	<u>Dielectric Strength Volts/Mil</u>
Epoxy	10	1000
Polyvinylchloride	10	400-500
Cellulose Acetate Butyrate	20-25	1000
Polyamide (Nylon)	10	1000
Polyethylene	10	900-1200
Chlorinated Polyether (Penton)	10	1000

Coating of torroidal coils, watt-hour meter coils, voltage regulator coils, motor stators and rotors and other electrical components too numerous to enumerate constitutes one of the largest uses of fluidized bed coatings.

MISCELLANEOUS SPECIAL APPLICATIONS

Many unique applications of fluidized bed coatings have been made to accomplish specific functional purposes. One of these applications consists of production of tamper-proof containers for various mechanisms, switches, or production of floats or other sealed bodies.

Figure 7 shows a sample salve can with slip fit lid hermetically sealed by coating with an epoxy resin. The sealing was accomplished by heating the container and contents to 425°F and allowing a short period of cooling to approximately 400°F before dipping in the fluidized coating material. The resulting falling temperature gradient and contraction of the air within the container produces a vacuum which draws a portion of the coating material between the faying surfaces of the lid and container during the period when the resin is in the fluid state. Continued existance of a vacuum within the container after curing at 390°F and cooling to room temperature is evident from the concavity of the lid and bottom.



CONTAINERS HERMETICALLY SEALED BY EPOXY
FLUIDIZED BED COATING PROCESS

FIGURE 7

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The excellent adhesion of the cured epoxy resin produces a seal which can not be opened without cutting the metal itself.

The technique just described can be used to eliminate soldering of lids on small containers, switches, electrical components with glass sealed leads, for producing inexpensive corrosion proof floats such as carburetor floats, for sealing and simultaneously coating seams between bolted flange structures and for covering and sealing dissimilar metal structures subject to environmental conditions which normally produce galvanic corrosion.

Fluidized bed coatings are used to eliminate the hand work of polishing sand castings as previously mentioned, and in addition are finding increased use in the coating of cast gear cases where the coating prevents loosely adherent casting sand from entering vital bearings or gears. An additional benefit is the prevention of catalytic oxidation caused by contact between the lubricant and the metal case.

Repair of Holes

The repairing of holes in castings and sheet metal containers is accomplished by placing a strip of high temperature pressure sensitive aluminum tape across the hole or defect and applying a heavy fluidized bed coating.

Nonfreezing Components

Parts in sliding contact, when subject to condensation of moisture on their surfaces, will frequently freeze to an immobile state due to tightly adhering ice formed when the temperature drops below the freezing point. It has been found that if the components of the assembly are epoxy coated, machined, and then treated with a silicone water repellent, the assembly can be deliberately water soaked and frozen to -70°F without ice adhering to an extent that it will prevent motion between the sliding surfaces.

Shatterproof Glass Containers

Glass bottles, plates, and jars when given a polyethylene, soft vinyl or nylon coating are simultaneously made shatterproof and are provided with an overall decorative color. Many materials which cannot be shipped or handled in plastic containers can thus be shipped in glass containers which have been made less dangerous by the fluidized bed application of a tough flexible plastic film. Though the glass may be broken, the coating will contain the fragments and contents.

DETAILS OF COATING APPLICATION

Fixturing and Handling

Many ingenious systems have been developed to solve the problem of handling the heated parts through the preheat, dipping and post-heating cycles. Methods range from elaborate cold fixtures to simple wire hooks, threads, or tongs.

Where long production runs of parts requiring some masked areas are encountered, the masking and handling problems are often solved by passing the part to be coated through the preheat oven on a conveyor belt or on dollies. As the heated parts emerge from the oven, a tong-like device is clamped on the work piece in such a manner to physically cover the areas to be left uncoated. A handle or hook which is part of the device is used by the operator to facilitate dipping the component and placing it in the post-heat oven. The cold metal or Teflon device prevents the powdered resin in the fluidized bed from reaching the hot surface where masking is desired. This technique has many ramifications. A simple tapered wooden plug driven into a hole will both mask the hole and provide a handle. A tong-like device similar to a vice-grip plier fitted with a pointed dowel pin on each jaw may be clamped securely into opposite ends of a hole to provide a cool handle which can be quickly attached and detached by the operator.

Many parts are merely placed into a fixture by the operator who uses asbestos gloves. A quick clamping device securely fastens a band or clamp so as to hold the part in a trunioned frame where it may be rotated in the fluidized bed without danger of dropping the part. Rotation of the parts within the bed or as they emerge from the fluidized bed is necessary where cup shaped parts or parts with horizontal shelf-like surfaces which collect large quantities of the powder are being coated. Here the fixture is rotated so as to dislodge the excess powder as the part is removed from the bed. Rotation within the bed is also used to obtain uniform coating action in depressions and corners on the underside of the work piece where bubbles collect and prevent further coating during the dipping operation.

Where a single small area of uncoated metal may be acceptable, a clean iron wire may be resistance butt-welded or copper or brass wire may be silver soldered, or brazed to the part. After coating, the wire is clipped off at the coating surface.

In many instances it is desired to obtain complete coverage of the object to be coated without contact marks. This is especially true where the part being coated will encounter severely corrosive action at any break in the coating. In these instances, (temperatures permitting), a nylon monofilament is tied onto the part and after coating, is clipped at the coating surface. It has been found that the epoxy resins adhere satisfactorily to the nylon to produce a pore free coating. The springs shown in Figure 1 have twisted nylon loops for dipping and curing. Hermetically sealed cans shown in Figure 7 were similarly handled. The thread was placed between the slip-fit lid and the bottom of the salve can. Then the can was opened, it was found that the epoxy resin had been drawn into the can alongside of the thread and a small adherent plug seal had formed.

Large diameter loops of stiff wire placed in holes in the part minimize contact marks and provide loops which can be hung on hooks on conveyors, racks or trolleys. In hand dip installations, this method offers some advantages in making the hanging of parts in the curing oven easy. In some cases where cold fixtures are used, the fixture may have to remain on the piece through the post heat or cure oven to permit hanging without contact marks.

Masking

While one means for masking (cold fixturing) has been described, several other methods have been devised.

Teflon plugs offer the most attractive means for masking holes where no coating is desired. These plugs may be used repeatedly due to lack of adherence of the coating. Silicone rubber plugs and shields may also be used in masking many of the coating materials.

Many materials such as aluminum foil and thin silicone grease films have been used for masking. However, the various pressure sensitive tapes have seen the most universal application. Paper masking tape is used with the lower temperature epoxy coatings. While the cost of glass cloth electrical tape is considerably higher than paper masking tape, it has the advantage of retaining its strength after the cure cycle. Where large areas are to be masked, several layers of Kraft paper taped in place adequately reduce heat transfer and eliminate waste of coating materials on masking materials. Wherever the pressure sensitive tape is used, it is best to remove the tape while the object is still hot. Any adhesive remaining on the metal surface usually is removed with petroleum solvent.

In many cases, the cost of labor and materials for masking are greater than the cost of coating materials applied to the area it is desired to leave uncoated. Where this is the case, the coating may be applied to all surfaces and later removed from the area by machining or, in the case of the epoxies, may be removed by power wire brushing with resin bonded brushes.

Stripping

Removal of coatings from unsatisfactorily coated parts is a problem of considerable magnitude. The substantially greater thickness of fluidized bed coatings than normal paint films is the principle reason for the difficulty in their removal.

Vinyl coatings may be stripped in solvent type strippers.

Unprimed polyamide (Nylon) can be stripped in boiling water as previously noted.

The epoxy coatings present a most difficult stripping problem. While excellent strippers capable of removing substantial thicknesses of cured epoxy coatings are available, even these require considerable time, their cost is high and most are expensive and quite corrosive to the skin. It is therefore very desirable that the number of parts requiring stripping be held to an absolute minimum. This may be accomplished by using a special procedure which takes advantage of the solubility of the uncured resin in trichloroethylene. If the parts are preheated, dipped into the fluidized epoxy resin and allowed to cool, they may be inspected for thickness, coverage and smoothness. Any rejected parts to be stripped need only be placed in a trichloroethylene vapor degreaser for a short period of time. Usually the entire coating will be removed in less than ten minutes.

The time required for removal of the coating is a function of both the temperature of the part at the time it is dipped and the mass of the part. For instance, most producers of epoxy coatings use preheat temperatures in the range of 390 - 425°F followed by a fifteen minute cure at the same temperature. Before curing, the coating may be removed in trichloroethylene in five to ten minutes. After curing, only a slight swelling of the coating occurs after two hours treatment in the degreaser. If, however, the parts to be coated are preheated to 500°F some curing occurs during the coating cycle and the trichloroethylene degreaser removes only the outer portion of the coating leaving the thin layer of the cured coating on the metal surface. It is therefore

desirable to use the lower temperature application if inspection and trichloroethylene stripping is to be employed.

The stripping procedure just described has several drawbacks worthy of mention.

1. In the uncured state, the coating is brittle and easily chipped. Therefore, considerable care must be exercised to prevent damage to the coating during inspection and handling.

2. When highly thixotropic resins are being used to obtain good corner coverage, the coating gels in a very short time and does not reflow unless placed in the curing oven before the gelling occurs. Therefore, some sacrifice in smoothness may be required when the parts are allowed to cool after applying the coating.

3. Where white pigmented epoxy coatings are being applied, any handling with the bare hands will result in yellow stains on the coating surface.

4. Fuel costs are increased due to the need for cooling followed by reheating to the cure temperature after inspection.

Stripping of the cured epoxy coatings is relatively a slow process. Acid type strippers or the type of diphase carbon removers used for internal combustion engine cleaning will satisfactorily remove the coatings. If the coating surface is scratched or otherwise abraded prior to immersion in the stripper, more rapid stripping action is obtained.

Coating Thickness Control

In many applications of fluidized bed coatings, thin coatings are desired. Control of the thickness, as previously noted, is largely a matter of the skill of the operator, the preheat temperature, the duration of the dip, and the density of the bed.

Density of the bed determines success or failure in obtaining uniform, pinhole-free thin coatings. The greater the density, (i.e., richer the bed), the shorter the dip time required to produce a thin coating.

Very thin coatings require the use of only sufficient air to bring the plastic powder into the fluid state. A very quick dip into this bed will allow maximum impingement of individual particles in the shortest possible dipping time,

thus making possible the complete coverage of the surface. One technique involves use of a minimum air volume for fluidizing and turning off this air just as the part is dipped. Thus, a rapidly enriching bed is obtained. This provides the ultimate in conditions best suited to obtaining thin coatings. Ordinarily, if a part is quickly dipped into a fluidized bed expanded the usual forty percent with air, the coating obtained will be found to be uneven and covered with pinholes. This condition is encountered because the highly attenuated bed produces too few impingements of particles of resin to form a complete coating during the short immersion time used. Therefore, higher density beds obtained by using just enough air to fluidize the resin is required for producing thin coatings.

COATING DEFECTS AND THEIR CAUSE

Epoxy Coatings

Pin Holes and Thin Uneven Coverage - This type of defect is usually the result of too much fluidizing air for the quantity of resin in the bed. Too great an attenuation of the resin allows too few particle impingements to provide complete coverage of the surface before the object cools below the sintering temperature. Either the fluidizing air should be reduced or more epoxy powder should be added to the bed.

"Orange Peel" Surface Condition - Thin sections are frequently heated to higher temperatures than those required for coating because of their poor heat capacity and rapid cooling. Under these circumstances, the coating is formed quickly but insufficient heat capacity remains to complete reflow of the coating before the temperature of the part drops below the reflow temperature. This type of defect is difficult to eliminate. However, selection of a less thixotropic resin and rapid transfer of the part from the fluidized bed to the curing oven will aid in producing a smoother coating.

Brittle, easily Chipped Coatings - Brittle, easily chipped coatings are generally the result of an insufficient cure. If the coated part is cured for too short a time or at too low a temperature, this condition is encountered. Resins containing dicyandiamide curing agent have a minimum cure temperature of approximately 300°F. Complete curing of the resin at this temperature would require many hours to develop the desired tough adherent film. At 500°F the same resin will cure in a period of five minutes. Intermediate temperatures require curing times intermediate between these extremes.

For instance, at 400°F, a period of fifteen minutes results in a complete cure.

In resins employing anhydride curing agents, the resin may fail to cure if moisture in the fluidizing air has converted the anhydride to the corresponding acid which has no curing properties.

Chipping may occur when epoxy coatings are applied to bright cadmium deposits which have not been bright-dipped to remove the adsorbed organic brightening agent.

Oil films, loosely adherent oxide layers and chromate conversion coatings on aluminum all produce poorly adherent coatings highly susceptible to chipping. Oil must be thoroughly removed and any oxide removed by chemical, mechanical, or abrasive means.

Due to the susceptibility of the epoxy resin to oxidation by chromates and the relatively poor adhesion of the chromate coating to the aluminum, these coatings should not be used under epoxy coatings.

Bubbles Or Isolated Pores in the Coating - Any volatile material on the surface or within the pores of the metal may produce gas bubbles in the coating if the parts are not properly cleaned prior to preheating and coating.

Isolated Rough Spots Or Nodules - Dirt, lint, fine metal chips or fragments from stop-off materials codeposit with the plastic and cause this type of defects. Little can be done when this condition exists. However, strict cleanliness of the coating area and the work being processed will prevent contamination.

Vinyl Coating

Heavy Lumps In Coating - Vinyl resins have a tendency to agglomerate upon standing or during shipment. Unless thorough screening to break up lumps has been carried out, these may attach themselves to the work surface where they present an unsightly defect.

Porous Coatings - Too high a post-heat temperature tends to cause surface fusion of the vinyl material before complete release of air from the underlying layer. Reducing the post-heat temperature will correct this condition.

Blistered Or Porous Coatings - Blisters in the coating are caused by excess primer such as droplets, runs or sags.

Where wire goods are being coated, excess primer is frequently retained where wires cross. The greater quantity of primer at such points dries slower than that on other portions of the part and the remaining solvent causes blisters when the part is preheated and dipped in the fluidized vinyl. In many dip priming applications some means for detearing, such as the use of an air blast, wire wipers or electrostatic, detearing is a necessity if blisters are to be avoided.

Blisters also result if the post-heat temperatures are too high. Under these circumstances the coatings fuse on the outer surface before the inner sintered vinyl material can fuse and release the air entrapped within. Lower post-heat temperatures together with longer post-heat periods will generally correct the difficulty.

Scorching Or Discoloration - Too high a preheat or post-heat temperature may result in blistering and browning of the coating. Discoloration of the coating may be the result of either too high a temperature or too long a post-heat time. Shortening the post-heat time cycle will prevent discoloration.

When the mass of a part varies, the rate of increase in both preheat and post-heat temperature also varies; spotty scorching may result. A longer heating period at a slightly reduced temperature will minimize temperature differences and help to avoid localized scorching.

Poor Edge Coverage - It is characteristic of the vinyls to have low strength at elevated temperatures. This, together with the relatively high surface tension of the molten plastic results in poor edge coverage if the post-heat or preheat temperature is too high or the preheat or post-heat time cycle are too long. Careful adjustment of both post-heat temperature and time will add to the strength.

Poor Adhesion - Insufficient drying time after prime coating will impair adhesion. Too high a temperature or too long a period of preheating will degrade the primers and also produce poorly adherent coatings.

As in the case of most protective and decorative coatings, failure to provide a clean properly pretreated surface will impair the adhesion of fluidized bed applied vinyl coatings.

Cellulose Acetate Butyrate Coatings

All of the defects experienced in the application of vinyl coatings also apply to cellulose acetate coatings. In

addition, certain other characteristic defects encountered are discussed below.

Crazing and Hairline Cracks - Embrittlement of the cellulose acetate butyrate coating may occur as a result of selection of incorrect preheat or post-heat cycles. Thermal degradation of the coating causes hairline cracks and usually produces a change in color of the coating. Oxidation of just the surface of the coating may occur, or in more severe cases, embrittlement of the entire coating is encountered where the entire coating has been overheated during excessive preheat temperature-time cycles. This condition is most often encountered where the preheat temperature is raised to eliminate the need for post heating for reflow of the coating. Downward readjustment of either the temperature or time of preheat can be made to eliminate this type of defect.

Russ and Sags - The high fluidity of cellulose acetate butyrate at the higher dipping temperatures and longer preheat times may produce sags or runs, particularly when excess powder is not quickly removed from areas where it may collect. This condition may be corrected by reducing the preheat temperature-time cycle to obtain a "sugar" coat followed by as short a post-heat reflow period as will eliminate "orange peel" and create the desired glossy finish.

Adhesion - Over-curing the primer through use of too high a preheat temperature may result in poor adhesion.

Nylon

Oxidation - Nylon is highly susceptible to thermal degradation and will darken and embrittle perceptibly if either the preheat or post-heat temperatures are too high or the part is held at the post-heat temperature longer than is necessary to produce the desired reflow. It is desirable to cool the coating as quickly as possible after the reflow. This may be done on automatic dipping lines by water spray cooling after post heating or may be accomplished in hand dip lines by quenching in water. The coating must be allowed to cool to 200 to 250°F before quenching to avoid the problem of the coating pulling away from edges due to the rapid contraction induced by the cold water.

FUTURE PROSPECTS FOR FLUIDIZED BED PROCESSES

An indication of the bright future of the Fluidized Bed Coating Process is evident when reviewing the extent of its application in the few years since its inception. Electrical

insulation, corrosion resistant coatings, wear resistant load bearing coatings, coatings for hermetic sealing, and coatings for decorative effects represent only the beginning of an even greater utilization of the process.

Improved curing systems for the epoxy type coating will further reduce the application temperatures required, improve flexibility and resistance to chipping. Urethane-epoxy and polyamid-epoxy copolymers utilizing the compatible curing agents will broaden the range of utilization by enhancing the flexibility, chemical resistance, malleability, and ease of application of the coatings.

Thermo-plastic material requiring no primer to obtain adequate adhesion will replace the somewhat troublesome priming system currently in use.

Pigmentation will provide surface characteristics tailored to provide desired frictional, wear, non-icing, thermally reflective, or decorative effects.

While the above developments would provide more widespread utilization of the process, the most spectacular development potentials exist in the application of fluidized bed coating principles to other coating materials. Foremost among the most useful developments would be the application of low fusion point metal and metal alloy coatings to metal substrates. Fluxing techniques, preheating cycles and vaporizing flux additive to be incorporated with fluidized metal will bring about application of fused metallic coatings without the attendant difficulties involved in conventional hot dip galvanizing, tinning and lead-tin dipping. Large containers of molten metals would no longer be required.

Wax coating of wooden components will permit uniform impregnation and application of waxes to fine wooden furniture.

Glazes will be applied to ceramic insulators and other porous materials destined to be kiln fired. Dry glazing will eliminate non-uniform application, replacing the wet glaze application and eliminate the need for pre-drying and re-dry rejects.

Special heat reflective multiple-layer plastic-metal coatings for short exposure to high temperature blast impingement will meet a need for such coatings in rocketry and space applications.

Fluidized Bed Plastic Casting techniques, similar to the Shell Molding Process in some respects, will provide a new mechanized "powder casting" method for manufacturing some types of plastic items.

Development of electrostatic powder "spray" guns together with resins with lower preheat requirements will permit coating of large objects not suitable for coating by conventional dipping methods. A "tack" coating followed by fluidized bed dip and fusion treatment representing a variation of this method will eliminate the problems of handling large heated structures such as auto bodies, curtain wall building panels and other similar items.

The prospects for spectacularly revolutionary developments in this field of high quality specialty finishes is truly unlimited. Widespread adoption of the process is assured by its current successful operation in many diversified fields.

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